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A Search for Neutrons from Fusion in a Highly Deuterated Cooled Palladium Thin Film

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We have carried out an experiment to search for neutrons released from a thin film of Pd–10% Ir. A film of thickness ≈2000 Å was prepared by sputtering. The film was then cooled to 77 K and was charged with deuterons by low-energy ion implantation. Deuterium was incident on the film as neutral D and D_2 with a kinetic energy of 1000 eV. Paraffin was used as a neutron moderator and absorber, with a NaI detector to observe the 2.22-MeV γ-ray expected from neutron capture by hydrogen neuclei. The high local concentration of deuterons in the film could, in some fusion scenarios, have produced a high rate of deuterium fashion. If this happened, this implantation technique could form the basis of a viable fusion power generator. However, we observed no excess neutron production over background. We were also sensitive to 23.8-MeV γ-rays (from fusion producing ^4He) but observed no peak at this energy.

1. INTRODUCTION

The dramatic recent announcement by Fleischmann and Pons[1] and Jones *et al.*[2] of the observation of deuterium fusion in palladium at room temperature has excited the entire scientific world. Many scientists are now attempting to reproduce these experiments. Our experiment does not attempt to confirm or refute these results. Instead we have carried out an experiment aimed at revealing the mechanism of cold fusion, if it exists, and at increasing the rate of the reaction.

Fleischmann and Pons report substantial generation of excess heat from a heavy-water electrolytic cell with a palladium cathode, with a maximum excess power output of over 10 W. They also observe 2.2-MeV γ-rays from neutron capture in the light-water bath, but at a rate about six orders of magnitude below the rate of d-d fusion required to produce the energy release observed.

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Jones *et al.* also claim to observe fusion in an electrolysis experiment with palladium cathodes. In this experiment the evolution of heat was not measured, but fast neutrons were detected with a sensitive neutron spectrometer. A neutron signal was seen above background at the right energy to correspond to the reaction

$$d + d \rightarrow n + {}^3He. \tag{1}$$

The rate of neutron production was about 10^{-1} per s.

The reduced rate of neutron production makes a straightforward interpretation of these data difficult. However, the evidence for cold fusion is recent and still unconfirmed, and some of the observations may prove on further experimentation to be inaccurate or incorrect.

2. ENHANCED FUSION RATES FROM DEUTERIUM IMPLANTATION

We take the results described above as indications that nuclear fusion, involving deuterium, occurs in pal-

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ladium. We have tried to create a physical environment which could lead to a greatly enhanced rate of fusion.

Most conventional explanations of cold fusion require high deuteron velocities, to overcome the Coulomb repulsion acting between positively charged nuclei. Rafelski *et al.*[3] have studied a model of fusion of two deuterons confined to a sphere of radius r. The fusion rate is a very rapidly varying function of r. The radius required to produce a fusion rate of 10^{-23} is about 0.3 Å, smaller than a normal interstitial volume available to deuterium in palladium. Rafelski *et al.* also point out that the ground-state energy of a deuteron in such a site is large, around 400 eV.

Based on these calculations, we speculate that implanting deuterons in a palladium lattice cooled to a temperature of 77 K could lead to an elevated rate of deuterium fusion, for the following reasons.

(1) Deuterons can be implanted at high densities in a limited region of the lattice. Diffusion of the deuterons away from the region of implantation should be substantially reduced by lowering the temperature. This could lead to a high multiple occupancy rate of normal lattice sites. If fusion takes place at these sites, this should greatly increase the rate.

(2) Supose that the fusion is in fact taking place at exceptional lattice sites of some kind where the deuterons are confined to a smaller volume, increasing the fusion rate as described by Rafelski. The energy of implantation (1000 eV) would put more deuterons at these sites. The high general occupancy of normal interstitial sites by deuterons and the low temperature would tend to maintain the deuterons in these high-energy sites once implanted there. Thus charging a palladium crystal with a very high deuterium density could lead to an increase *by orders of magnitude* in the fusion rate.

We feel that the plausibility of these arguments justifies an experiment to search for fusion in palladium highly charged with deuterium, even at our relatively low neutron sensitivity.

3. THE EXPERIMENTAL SETUP

In this experiment we looked for neutrons from a cooled paladium thin film. The experimental setup is shown in Fig. 1. The film, of palladium–10% irridium,[4] was deposited by d.c. magnetron sputtering [(a) in Fig. 1]. An ion source[5] [(b) in Fig. 1] was capable of supplying beams of deuterons with an ion current of up to 100 mA and an accelerating voltage of 1000 V. The ions are neutralized after acceleration, to provide a beam of largely neutral atoms and molecules. The substrated ((c) on figure 1) consisted of a copper plate, soldered to copper tubes through which liquid nitrogen was circulated intermittently during the experiment.

The thickness of the film was monitored during its deposition by a quartz-crystal thickness monitor[6] ((g) on figure 1). This monitor measures changes in mass per unit of area of the film. This should have permitted us to monitor the deposition of the deuterium in the film, but uncertainties in the effects of heating by the ion source may have made these data unreliable.

Neutrons were detected in a moderator/absorber consisting of about 0.1 m^3 of paraffin, placed at one side of the vacuum system as shown in figure 1. The sodium-iodide detector ((d) in figure 1) was placed at the center of the paraffin. The NaI crystal was roughly in the form of a cylinder, of height 3 cm and diameter 5 cm.

4. DEUTERIUM IMPLANTATION

The goal of this procedure was to introduce energetically as many deuterons as possible into as small a

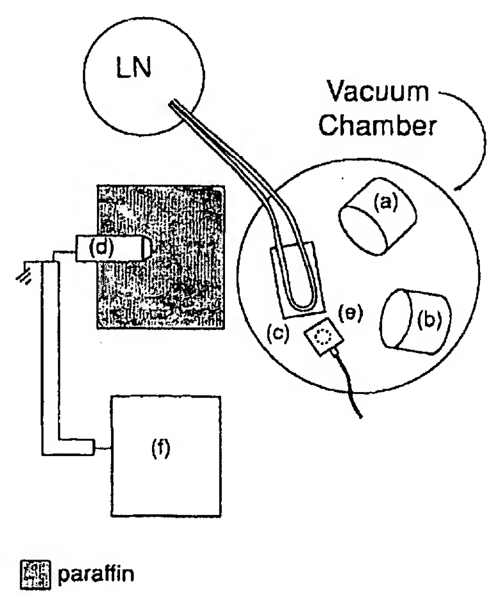

Fig. 1. Diagram of the experimental apparatus. The parts indicated are (a) 2-in. d.c. magnetron sputtering gun, (b) 3-cm ion source, (c) substrate cooled with liquid nitrogen, (d) NaI detector, (e) thin-film thickness monitor, and (f) multichannel analyzer.

volume of the palladium lattice as possible. Our ion source turned out to be nearly ideal for the purpose.

We do not have data on the range of 1000-eV deuterons in palladium. However, the Particle Properties Data Booklet[7] gives an energy-loss relation for protons in silicon. This relation gives a range for 1000 eV protons of 180 Å. It seems reasonable that the range of deuterons in palladium should be about the same.

We operated the ion source at 100 mA and 1000 V during the implantation. We estimate that the current density at the sample was about 2 mA/cm^2. The implantation at 77 K lasted about 1.5 h. This gave about 7×10^{19} $deuterons/cm^2$ incident on the film. For comparison, the surface density of palladium atoms in the 2000-Å-thick film is 1.4×10^{18}. This means that concentrations of up to 50 deuterons per palladium atom could be achieved, if (a) all the deuterons entered the film and (b) the deuterons did not diffuse out the front or the back of the film.

Some information on the adherence of the deuterons to the substrate should be available from the thickness monitor. We did in fact observe an increase in apparent film thickness during the exposure to the deuterium beam. If interpreted as being due to deuterons confined to the 2000-Å-thick palladium film, the corresponding ratio of deuterons to palladium atoms would be about 9. However, tests on the effect of heating of the thickness gauge by the ion source indicate that this figure may not be reliable.

5. CALIBRATION OF THE NEUTRON DETECTOR

The energy calibration for the NaI gamma-ray detector was determined with a ^{60}Co test source. This source gives γ-ray peaks at 1.17, 1.33, and 2.50 MeV. We calibrated the detector by recording the channel numbers corresponding to each of these peaks and fitting them with a linear relation between energy and channel number. This relation was subsequently used to calculate the energy for each bin. The ^{60}Co calibration was repeated several times in the course of the experiment.

The efficiency of our apparatus for neutron detection was measured by replacing the palladium film with a neutron source and recording γ-ray spectra. The data from one calibration run are shown in Fig. 2. There is a clear peak at 2.2 MeV, corresponding to the γ-ray from the thermal-neutron reaction

$$n + p \rightarrow d + \gamma(2.226 MeV) \qquad (2)$$

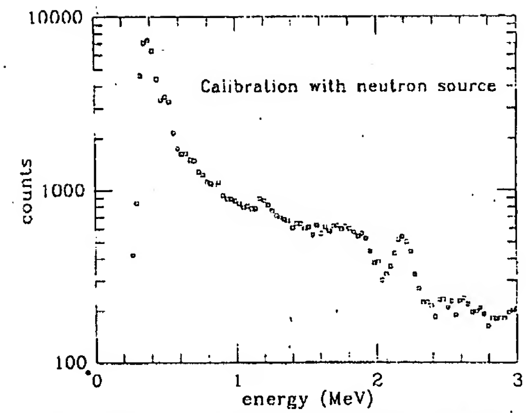

Fig. 2. Calibration spectrum to determine neutron-detection efficiency, taken with the thin-film sample replaced by a neutron source.

In this run of 156 s, the number of neutrons seen above background was estimated to be 1345.

The neutron source used was a 1-Ci Pu–Be source which should produce 2.2×10^6 neutrons per s.[7] Our neutron-detection efficiency is thus about 4×10^{-6}. This is a rather low efficiency, due principally to two factors: the NaI crystal of our detector, obtained on short notice, is a small one; and the constraints of carrying out the experiment in a thin-film deposition vacuum chamber led to a paraffin moderator/absorber of rather low efficiency.

6. GAMMA SPECTRUM DURING DEUTERIUM IMPLANTATION.

In Figs. 3 and 4 we show the γ-ray spectrum recorded from the NaI detector during the deuterium implantation. Figure 3 shows the spectrum up to 3.5 MeV, covering the range where γ-rays from thermal neutron capture by hydrogen are expected. We also show a background curve, obtained by recording a long background run, just after removing the palladium film from the deposition apparatus. The background curve is normalized to the data run using the ratio of counting times. There is no statistically significant difference between the two curves. The number of events over background in the region of the 2.2-MeV γ-ray line is 7 ± 9 counts. Taking into account our measured efficiency for detection of neutrons, this leads to an upper limit on neutron production during our ion-beam exposure of 800 neutrons per s (90% c.l.)

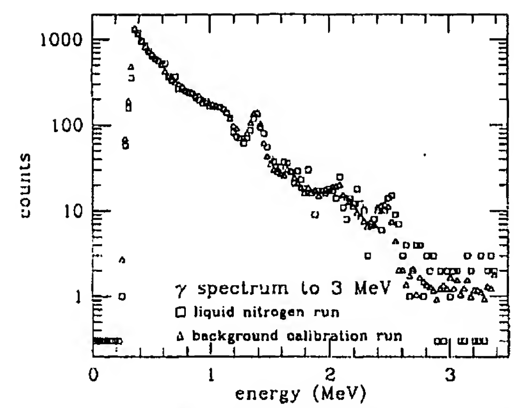

Fig. 3. Gamma-ray spectrum taken during deuterium implantation, over the energy range of 0 to 3.5 MeV. The squares correspond to data taken during deuteron implantation, and the triangles, to a background run taken directly after the implantation but with the palladium film removed. The background was scaled to match the data, by the ratio of counting times for the two spectra. The width of each bin is 0.029 MeV.

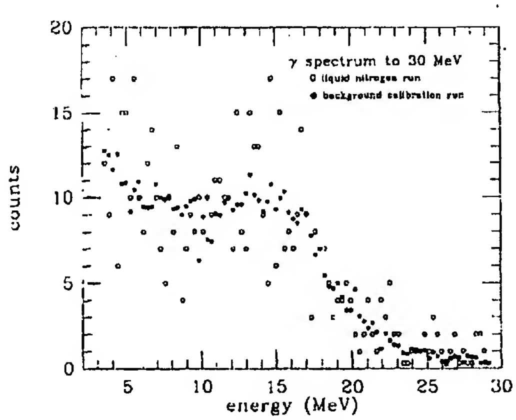

Fig. 4. High-energy γ-ray spectrum (3 to 30 MeV) taken during deuterium implantation and background. The background is determined in the same way as for Fig. 3. Bins have been combined on this graph, so that the energy width of each bin is 0.29 MeV.

Figure 4 shows the data and background for the energy range from 3 to 30 MeV. Bins have been combined. We see no peak near 23.8 Mev, with a 90% c.l. upper limit of about 7. The efficiency for these γ-rays is estimated rougly to be the geometrical efficiency of the NaI detector, 2.3×10^{-3}, divided by 2 for escape corrections. This gives a limit of 1.1 per s over the 1.5-h exposure for the reaction

$$d + d \rightarrow {}^4He + \gamma \qquad (3)$$

7. CONCLUSIONS

We have used a new technique to produce a high concentration of deuterons in a palladium lattice. If cold fusion is confirmed, this technique could prove useful in maintaining a continuous fusion reaction in a thin film.

We failed to detect neutrons or high-energy γ-rays from fusion in the palladium film during deuterium implantation. While this does not rule out release of neutrons at the rate observed by Jones *et al.*,[2] we have clearly failed to multiply the effect which they observed by a dramatic factor.

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